ANL/ESD-16/5

Development of an Agent-based Model to Analyze Contemporary Helium Markets

Energy Systems Division

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Development of an Agent-based Model to Analyze Contemporary Helium Markets

prepared by

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Contents

Notation

BAU	Business-as-usual
BLM	Bureau of Land Management
DLA	Defense Logistics Agency
MMcf	Million cubic feet
UML	Unified Modeling Language
ISO	International Standards Organization

1 Introduction

Historically, the U.S. Helium Reserve supplied about 40% of domestic and 30% of global helium demand. Passage of the Helium Stewardship Act of 2013 changed the resource allocation to a series of annual auctions along with in-kind[1] and conservation [2] sales after 2015. The auction process starts by offering 10% of the total sales from the reserve, increasing the amount another 15% by mid-decade and effectively doubling the amounts offered annually after 2020 until the reserve is depleted of salable gas. The Act also requires the government to price the helium it auctions at a level sufficient to cover the cost of maintaining and shutting down the reserve and calls for an assessment study of global helium demand trends.

Although U.S. helium demand has remained relatively flat since 2009, exports of helium have increased significantly since then, driven primarily by demand for electronic and semiconductor manufacturing in Asia. In the midst of this global demand shift, the Helium Act dictates a new procedure for pricing and distributing the gas through a reserve that historically functioned as a loose “oligarchy.” The new procedure requires prices to be determined by the open market through auctions and a survey of market prices, as opposed to increasing prices according to the consumer price index. Response to these changes has caused temporary shortages, price increases, and a significant increase in the development of the helium extraction technologies used to produce helium from formerly marginal sources. Technologies are being developed and refined to extract helium from formerly low-yielding natural gas fields containing much lower amounts of helium than the previously considered economic threshold of 0.3%. Combining these transformative policies with the potential for new and significant global supplies from Qatar, Algeria, and Russia could lead to new and unforeseen market behaviors and reactions from global helium markets.

2 Objectives

The objective of the project is to analyze the global helium markets. In particular, we try to answer the following three questions in this initial phase:

- Will the U.S. become a net importer under various demand scenarios?
- What will be the Bureau of Land Management’s (BLM’s) reserve trajectory under various demand scenarios?
- What might future price developments look like?

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[1] In-kind sales are sales of U.S. Helium Reserves that are designated for federal agencies and their contracting agencies. Private refiners buy the crude helium from BLM, refine it, and deliver it to the federal agencies.

[2] Conservation sales are sell-downs of U.S. Helium Reserves (pursuant to the 1996 Act) to (mostly) the refiners on the pipeline, with a yearly escalation of the price at the rate of increase seen in the preceding year’s consumer price index. The pricing procedure changed after the Helium Stewardship Act of 2013. Please see Section 3.2 for the new procedure.

We attempt to answer these questions by building a new tool that leverages the experience gained from prior work to develop a Global Critical Materials market model that examines similar market dynamics as applied to rare earth commodities. This new tool examines supply, demand, and pricing issues in the global helium market, which is similarly uncertain and is currently facing policy changes. The helium agent-based model allows us to explore the interactions among players in the global helium market and examines the flows of materials and capital from reserve to user application. It captures time lags within the system and imperfect and asymmetric information. The tool is developed in several stages. This report documents the first phase—the development of a prototype version.

3 Helium Background

3.1 History

The U.S. government has long considered helium as a strategically important gas, and helium has been the subject of much legislation. The history of government involvement in helium production is summarized in Figure 1.

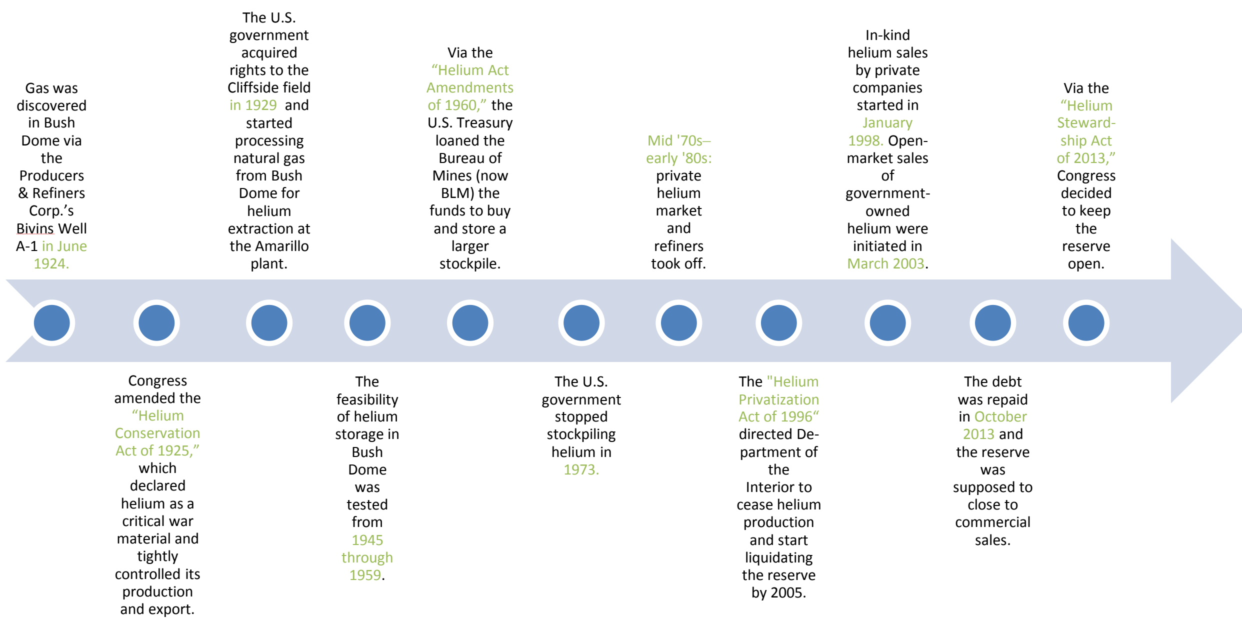

Figure 1 History of U.S. government involvement in helium production and storage

Helium, in most cases, is a by-product of natural gas extraction and processing. However, natural gas fields with high helium content, such that helium extraction is economically feasible, are limited. A gas with high helium content was discovered in Bush Dome in the Cliffside field in 1924. The Helium Conservation Act of 1925 was the first law to recognize the importance of helium. Following the act, the government acquired the rights to the Cliffside field in 1929 and started production at the Amarillo helium plant. During the cold war, the strategic value of helium became more obvious as it was an important element for scientific research and was used as gas for airships. In accordance with the

Helium Act Amendments of 1960, the U.S. Treasury loaned the Bureau of Mines (now the BLM) the funds to buy and store a large stockpile of helium. Since then, Bush Dome in the Cliffside field has been the only storage reservoir in the world supplying helium.

In 1973, the U.S. government stopped accumulating crude helium, as the reserve (35 Bcf) was far exceeding the annual consumption (650 million cubic feet or MMcf). Meanwhile, the private helium market and industry picked up. The Helium Privatization Act of 1996 directed that substantially all of the helium accumulated as a result of earlier policies be sold off by 2015 at prices sufficient to repay the debt to the federal government. In-kind helium sales (sales designated for federal agencies) started in January 1998. Open-market sales of government-owned helium were initiated in March 2003. The debt was repaid in October 2013, and the reserve was supposed to close to commercial sales. However, there was still gas in the reservoir. Since the federal helium reserve plays a significant role in the global helium market, its shutdown as directed by the 1996 Act would cause a significant decline and destabilization in the global helium supply. Hence, with the “Helium Stewardship Act of 2013,” Congress decided to keep the reserve open and continue commercial sales.

For further details on the evolution of helium production in the U.S., please refer to References [1], [2] and [3].

3.2 Helium Prices

Approximately one-third of world production was provided by BLM reserves in 2010. This fraction has been declining with new capacity coming online, especially in Algeria and Qatar. However, BLM prices still have a significant impact on global markets and determine the global helium prices. Currently, BLM sells crude helium through three channels:

1. Conservation sales (allocation);
2. In-kind (federal agencies and their contracting agents); and
3. Auctions.

The first step in setting all three prices is to determine an Open Market Crude Sales Price. A 2013 study by J.R. Campbell & Associates, Inc. [4], provided BLM with the methods and procedures to establish an end-user-based crude helium price for FY 2014 and beyond. The study proposed using the weighted bulk price from survey data as the basis for the Open Market Crude Sales Price, which is then used as the starting price (reserve price) for annual auctions. The conservation price is then based on auction prices and the Open Market Crude Sales Price; it is computed as the weighted average considering the percentages of conservation and auction sales. The in-kind price is set to 80% of the conservation price.

The sales targets of BLM for different channels are known and are given in Table 1 [5]. In addition to conservation sales, in-kind sales, and auctions, a portion of the helium reserve is already owned by private companies, so 20% of the volumes removed from BLM storage each year (excluding in-kind sales) is reserved for these private withdrawals from storage.

Table 1 Helium sales projected by BLM

Fiscal Year (FY)	Forecasted production capability (NITEC study) Mcf	In-kind sales Mcf	Total production available for sale/auction/delivery Mcf	80% Available for sale/auction Mcf	% of auction volume Mcf	Auction volume Mcf	Sale volume (Conservation) Mcf	20% Available for private storage delivery Mcf
2015	1,320,160	160,000	1,160,160	928,128	10%	92,813	835,315	232,032
2016*	1,158,150	160,000	998,150	798,520	25%	199,630	348,890	199,630
2017	997,450	160,000	837,450	669,960	40%	267,984	401,976	167,490
2018	848,280	160,000	688,280	550,624	55%	302,843	247,781	137,656
2019	714,430	160,000	554,430	443,544	70%	310,481	133,063	110,886
2020	606,130	160,000	446,130	356,904	100%	356,904	-	89,226
2021	537,880	160,000	377,880	302,304	100%	302,304	-	75,576

* According to the Helium Act, there is a one-time advanced sale of 250,000Mcf in FY 2016.

4 Information Sources

4.1 Data Sources

The data sources we used to develop the inputs for our prototype model include the following:

- National Academy of Sciences report on "Selling the Nation's Helium Reserve" [2]
- J.R. Campbell & Associates, Inc., "Determination of Fair Market Value Pricing of Crude Helium" [4]
- USGS – Mineral Commodity Summaries and Minerals Yearbooks [6]
- 2014 World Helium Market Report, CryoGas International [7]
- Cai et al., 2010 [8]
- E-mail contact with John Hamak (Lead Petroleum Engineer, Helium Resources) from BLM
- SMART (Strategic Materials Analysis and Reporting Topography) – Oak Ridge National Laboratory and Defense Logistics Agency (DLA) Strategic Materials

4.2 Industry Stakeholder Interviews

Early in the project, we engaged with a number of industry stakeholders to gain a deeper and more hands-on understanding of the helium industry and markets. The interviews were also conducted with the intent to obtain information and data directly from industry participants. The information we gained from these interviews helped inform our model development. The notes and conclusions from the stakeholder interview process are documented separately to preserve the confidentiality of the information.

5 Prototype Model Design

We created a prototype agent-based model of the helium market that captures many key aspects of helium markets. This section provides an overview of the agents, agent behaviors, and input data included in the prototype. We start the simulations in 2014, and run the model for 15 years, until 2029.

Data have been collected for the historical period from 1998 to 2014 for future calibration runs. The structure of the model, including all the components and methods, is shown in the Unified Modeling Language (UML) diagram in Figure 2.

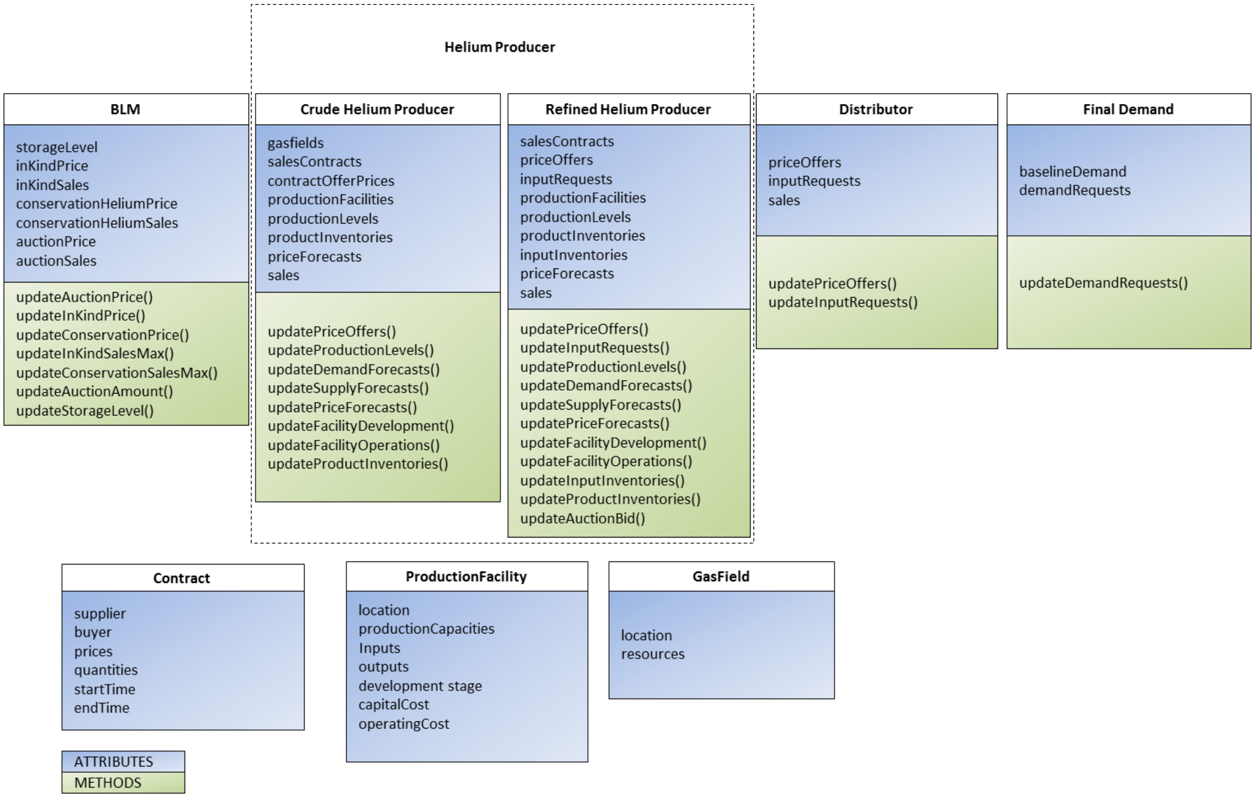

Figure 2 UML diagram of helium prototype model

5.1 Agents

The model includes a number of agents with various agent behaviors (Figure 3). The list of agents is as follows:

- 1 BLM agent with three different sales mechanisms: In-kind, auction, and conservation sales
- 21 private crude helium extractor agents, 7 of which are on the BLM pipeline. These include the crude extraction portion of integrated producers that both extract and refine helium.
- 20 refined helium producer agents, 6 of which are on the BLM pipeline
- 4 distributor agents, one for each of four producing regions
- 36 final demand agents representing 5 regions and 7 consumption categories, plus one in-kind demand agent

Each agent has different decision rules and behaviors, as discussed below.

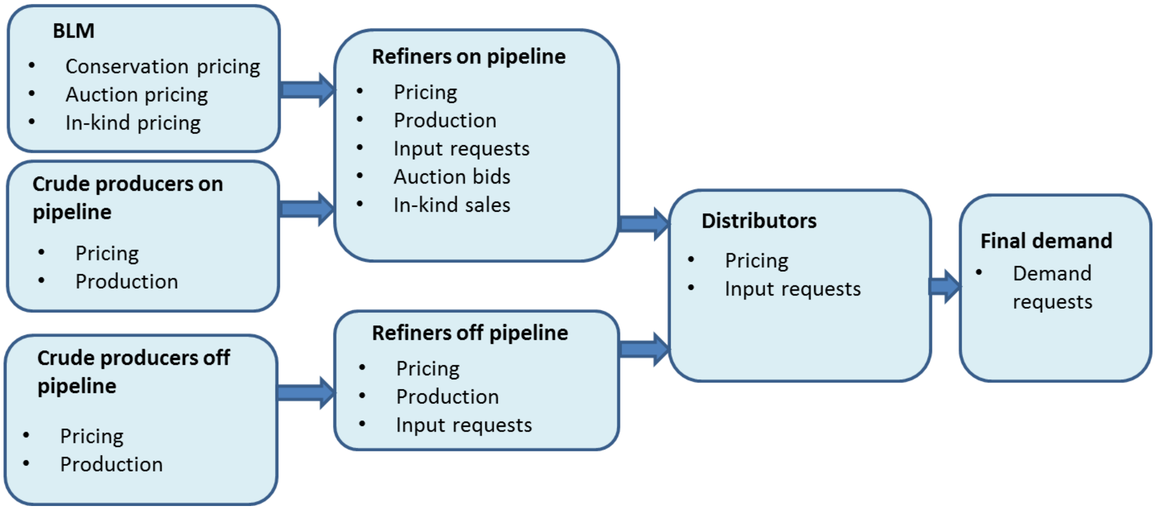

Figure 3 Helium model agents and agent behaviors

5.1.1 BLM Agent

The BLM agent has the following decision rules and behaviors:

- Setting conservation, in kind and auction sales
    - Through 2021, the amounts available for conservation, in-kind and auction sales are limited by BLM published amounts. Deliveries of private storage are not modeled, and private storage is not included in BLM reserve volumes.
    - After 2021, it is assumed that 15% of the remaining reserve is sold each year. Of this, 160 MMcf/year is sold as in-kind, and the remainder is sold through auctions.
- Setting open-market price
    - The open-market price is calculated to be 55% of a weighted average of the helium price paid by final demand agents for bulk deliveries in ISO containers or tube trailers.
- Holding auctions
    - Opening bids are at open-market price.
    - Supply is fixed, while demand responds to prices.
    - If demand exceeds supply, the price is raised until demand equals supply.
- Setting conservation price
    - Conservation price is a weighted average of the open-market price and the auction price, with the weights based on the proportion of conservation sales to auction sales.
- Setting in-kind price
    - In-kind price is set to 80% of the conservation price.
    - If there are no conservation sales (after 2019), then it is 80% of the auction price.

5.1.2 Crude Producer Agent

The Crude Producer agent has the following decision rules and behaviors:

- Facility Development
  - Potential new facilities and capacity expansions are specified in the input data. Crude producers decide whether or not to develop these new capacity options on the basis of calculations of expected profitability using forecasts of helium prices.
- Price setting
  - Crude producers set prices on the basis of their demand relative to their capacity, their cost, and the prices of competitors.
  - Crude producers who are on the pipeline use BLM price.
- Production
  - Crude producers produce enough to meet demand, up to a capacity limit.

5.1.3 Refiner Agent

The Refiner agent has the following decision rules and behaviors:

- Pricing
  - Refiners set prices on the basis of their demand relative to their capacity, their cost, and the prices of competitors.
- Production
  - Refiners refine enough to meet demand, up to a capacity limit and a limit based on the amount of crude they are able to purchase.
- Input requests (crude purchases)
  - Refiners buy enough to meet their production needs.
  - If they have more than one potential supplier, they choose whom to buy from on the basis of the relative prices offered by different suppliers, and their reliability (based on past experience).
- Auction bids
  - When auctions are held, refiners who are on the pipeline choose how much to bid in the auction.
- In-kind sales
  - In-kind helium that is purchased is marked up following a fixed formula and sold to distributors.

5.1.4 Distributor Agent Behaviors

The Distributor agent has the following decision rules and behaviors:

- Pricing
  - Distributors add a fixed cost to the refined helium cost, which differs depending on the distribution method, and then multiply by a fixed markup of 10%.
- Input requests (refined-helium purchases)
  - Distributors buy enough to meet their demand, and choose whom to buy from on the basis of the relative prices offered by different suppliers, and their reliability (based on past experience).

5.1.5 Final Demand Agent Behaviors

The Final Demand agent has the following decision rules and behaviors:

- Demand requests (distributed helium purchases)
    - Final demand agents adjust their demand levels in response to helium prices with a price elasticity parameter (default value 0.4) and choose whom to buy from on the basis of the relative prices offered by different suppliers.

5.2 Model Inputs

An Excel sheet with detailed model inputs has been prepared as the basis for the prototype model runs. Additional model inputs can be set via model parameters. The input data and parameters include the following:

- Demand projections from 2014 to 2029 by region and type of end use
- Crude facilities with their production capacities and assumed costs
- Refining facilities with their production capacities and assumed capital and operating costs
- Potential new crude and refining facilities and capacity additions to existing facilities, with their earliest possible start time and assumed capital and operating costs
- Information about relationships between buyers and sellers of crude, refined and distributed helium (i.e., who could potentially buy from whom), and the portion of each buyer's purchases that initially come from each potential supplier (in 2014). Appendix A illustrates the initial regional flows used as the basis for these relationships.
- Historical prices for different helium products (currently, only the 2014 numbers are used)
- BLM's planned helium sales via each of the three channels (conservation, in-kind and auction), and historical storage levels (used only for 2014 values)
- The types of distribution methods (with proportions) used for each final demand category and region
- Price elasticity of demand
- Demand growth adjustment

6 Model Results

We generated results to address three questions to test the prototype model:

- What will be the BLM reserve trajectory under various demand scenarios?
- What might future price developments look like?
- Will the U.S. become a net importer under various demand scenarios?

We demonstrated the prototype model by generating model results under three demand scenarios. We also explored alternative supply scenarios, including one with a decline in U.S. supplies. While the results are preliminary, given that this is only a prototype model, they nonetheless can provide some useful insights.

Figure 4 shows reserve trajectories under three demand scenarios:

- Low demand growth: 0% growth in business-as-usual (BAU) demand after 2014

- Medium demand growth: 2% growth in BAU demand worldwide after 2014
- High demand growth: 5% growth in BAU demand worldwide after 2014

In all scenarios, reserves will be close to being depleted by 2029, but some helium will remain in the ground. The depletion rate does not depend greatly on the rate of demand growth. The timing of the depletion of helium reserves may be of interest to policy makers as they weigh any additional action that may be needed to ensure continued functioning of the market in the absence of government reserves.

Figure 5 shows that both flat and rapidly increasing price trajectories are possible, depending on the rate of growth in demand, and that an increase in supply can reverse a trend of increasing prices. The potential for large price increases in the high-demand-growth scenario indicates that additional new supplies could be needed to keep the market in balance if helium demand growth resumes. As reserves are depleted, BLM prices rise above average private crude prices because of a supply shortage on the pipeline. This leads to an increase in BLM prices and private crude prices on the pipeline, but prices off of the pipeline do not increase as much, and so the average private crude price does not increase as much either.

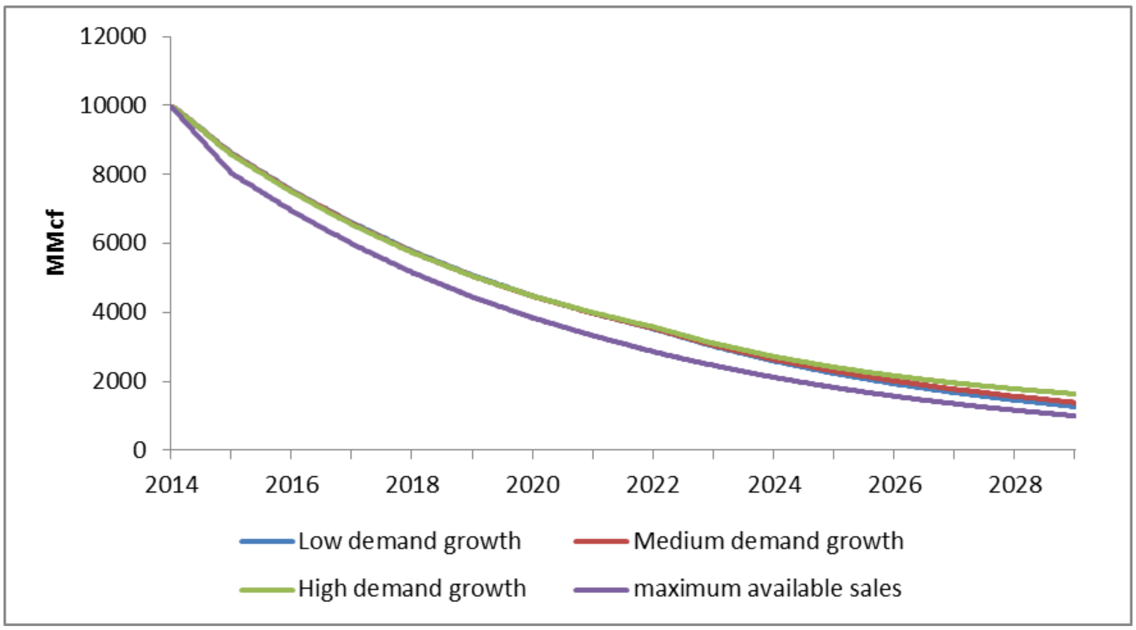

Figure 4 Helium in BLM storage

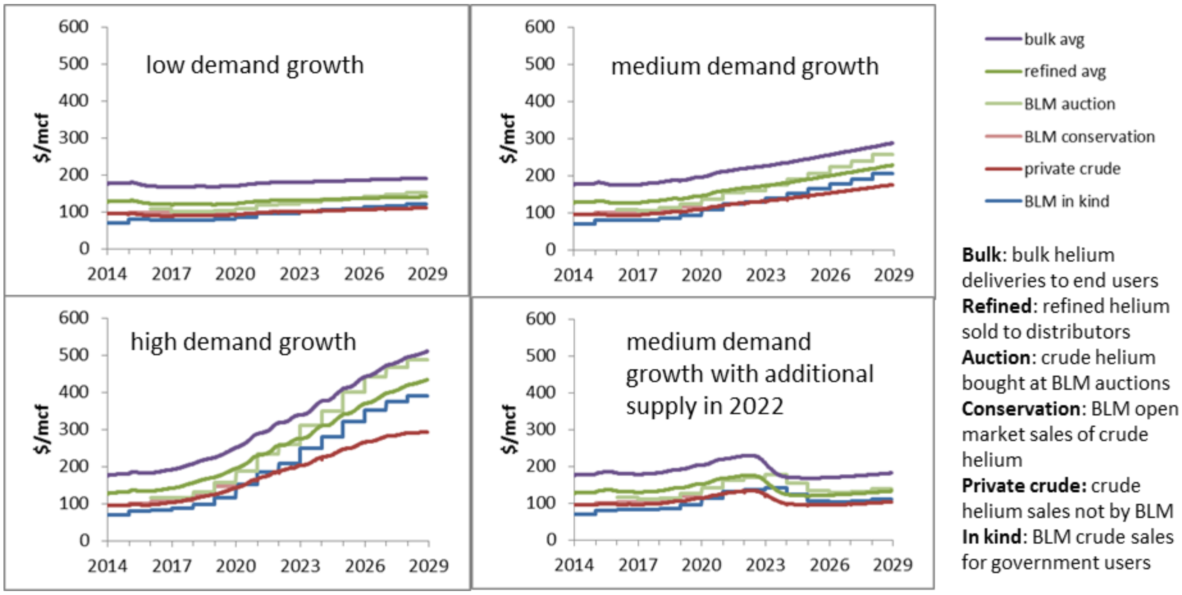

Figure 5 Prices of six helium products and markets under four scenarios

We conducted a sensitivity analysis to explore how U.S. net exports respond to different assumptions regarding demand growth, new capacity additions, and depletion of existing reserves. With default assumptions, the U.S. net exports drop from 2,029 MMcf to 1,361 MMcf over the course of the model run from 2014 to 2029, but the U.S. remains a significant net exporter of helium throughout that period. The assumptions behind this run include a 2% growth in exogenous demand in all regions of the world, no decline in production capacity from existing fields, and new production only coming from four sources for which we have data (two domestic and two foreign). As shown in Figure 6, adjusting demand growth rates throughout the world has some impacts on net exports, but the effects are fairly small. Higher demand growth actually leads to an increase in net exports because production and sales in all regions are higher in the higher-demand scenario, as producers push their capacity constraints as much as possible to try to keep up with demand, leading to an increase in all sales, including exports.

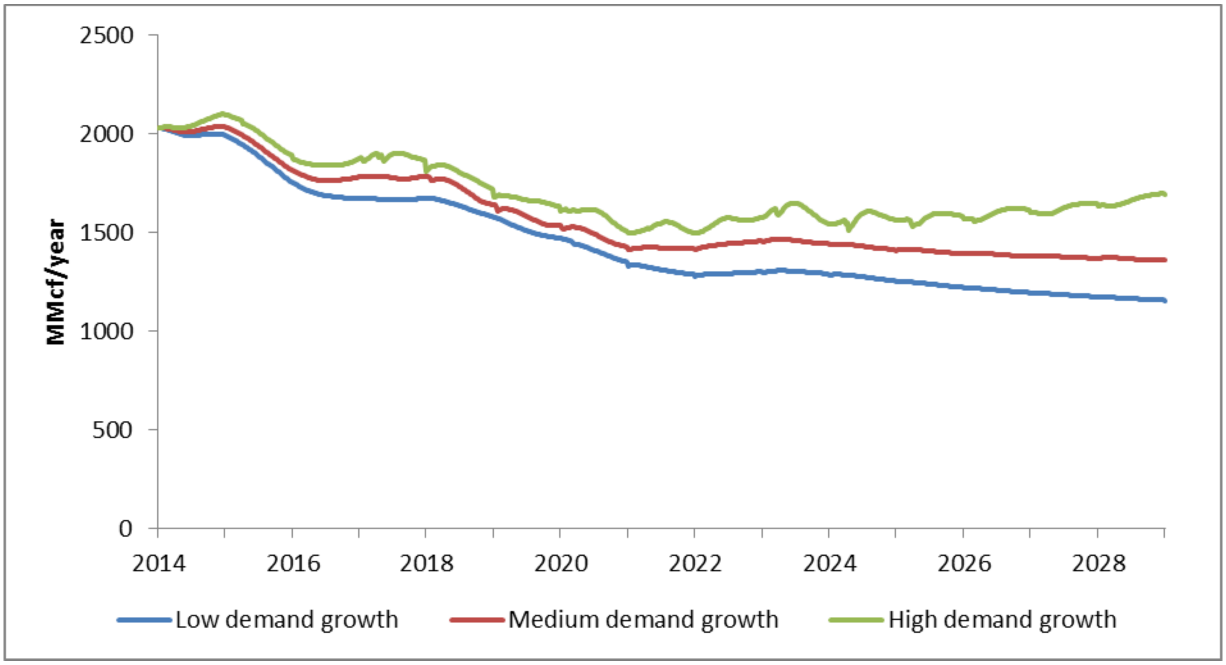

Figure 6 U.S. net helium exports -- demand growth scenarios

If new supply from outside of the U.S. comes online to meet this new demand, this can lead to a significant drop in U.S. exports: for a 34% increase in projected non-U.S. capacity (1,500 MMcf), we find that net exports drop 37% relative to the baseline in 2029, and for a 67% increase in non-U.S. capacity (3,000 MMcf), we see a 65% drop in net exports. However, for the U.S. to become a net importer of helium, a total of 5,400 MMcf of new supply from outside the U.S. would need to be added, which would amount to a 121% increase in projected 2018 non-U.S. capacity. Figure 7 shows three alternative scenarios with increased non-U.S. supplies, compared to the baseline high-demand-growth scenario.

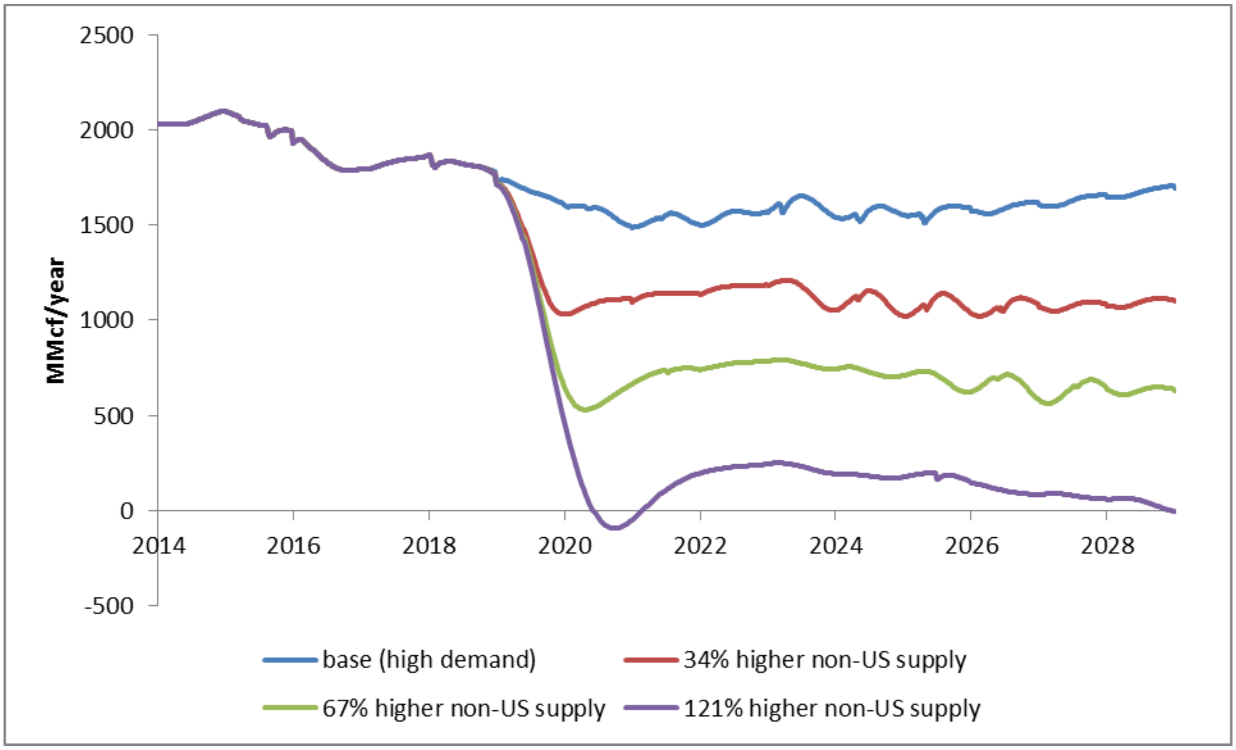

Figure 7. U.S. net helium exports -- non-U.S. supply scenarios

Another factor that we may not be capturing in the default scenario is that fields on the U.S. pipeline are mature and may experience declining production in the future. We explore a scenario in which production from these fields declines 7% per year starting in 2015. This scenario also leads to a substantial drop in U.S. exports (48% lower in 2029 than without field decline), but on its own it is not enough to make the U.S. a net importer, as more recently developed fields such as LaBarge are enough to cover U.S. demand in the absence of an increase in foreign supply. However, a combination of high demand, increased non-U.S. supply, and declining U.S. fields could make the U.S. a net importer. For example, a 5% demand growth combined with a 67% increase in non-U.S. supply and a 7% decline rate in fields on the BLM pipeline leads to the U.S. becoming a net importer of 107 MMcf of helium by 2029. However, this scenario requires not only large increases in non-U.S. supply and declining U.S. fields, but also very limited capacity addition in the U.S. Additional new U.S. supplies beyond those that are already included could help preserve the U.S. status as a helium exporter. Figure 8 shows the effect of additional non-U.S. supply and U.S. field decline, in isolation and in combination.

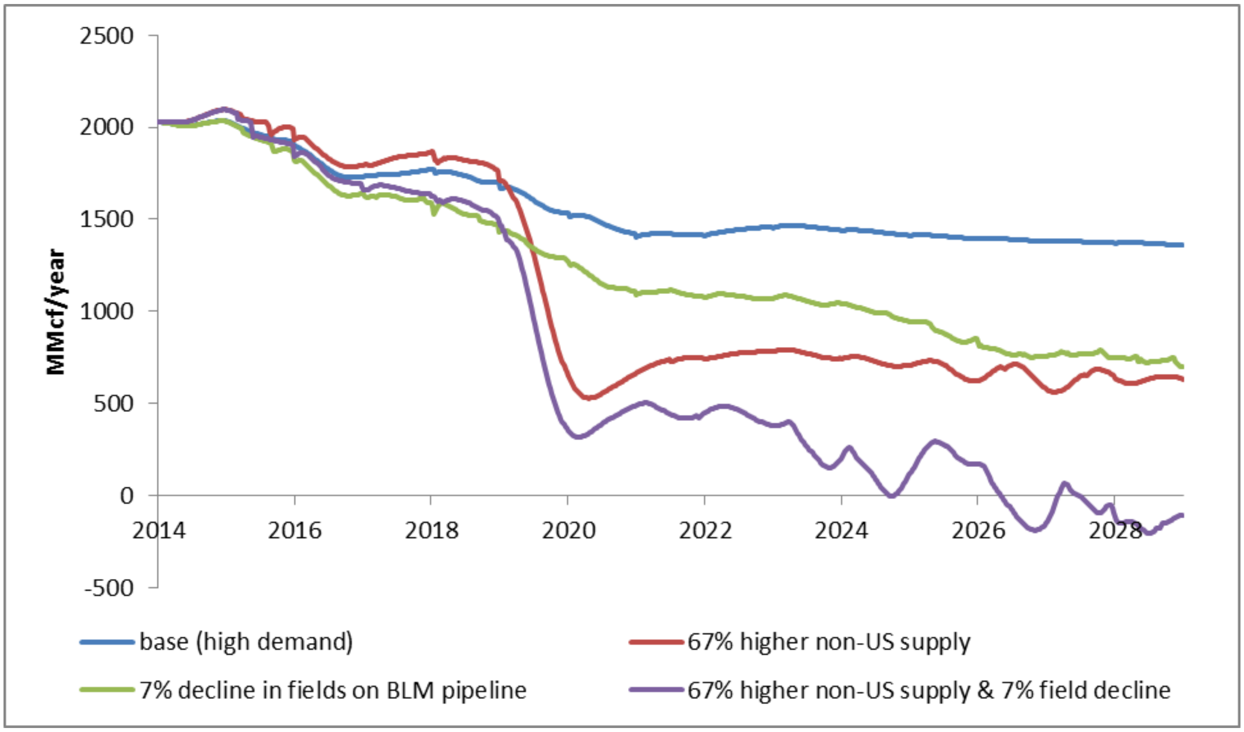

Figure 8 U.S. net helium exports -- combined scenarios

7 Conclusions and Next Steps

In stage 1, we conducted stakeholder interviews, collected data on helium markets, and generated a prototype agent-based model of the helium markets. We delivered a working copy of the prototype model to the Department of Energy's Office of Energy Policy and Systems Analysis. Our results demonstrate that the prototype model captures key features of the helium supply chains and produces reasonable market responses to different demand and supply scenarios. They also demonstrate the potential of the model to answer important questions about helium markets. Through scenario evaluation and sensitivity analysis, the model enables us to evaluate the conditions that would have to occur for the U.S. to become a net exporter, and improves our understanding of which assumptions and future developments could have the most impact on these outcomes.

In future work, we hope to extend this prototype model and conduct scenario analyses to address additional questions. In the near term, some questions we could potentially answer include the following:

- What agent behaviors and market conditions could explain the patterns observed in the historical data from 1998 to 2015?
- Under what scenarios will helium prices be high enough to stimulate new helium production?
- What would be the price or supply impacts of extended or significant maintenance outages for domestic plants or geopolitically-forced outages for international plants?
- What would be the price and supply impacts if widespread hydrogen substitution were employed for lifting and semiconductor manufacturing or other inert gases were employed for welding?

- There seems to be a lot of movement towards more efficient use of recycling of helium used in MRI scanners. MRIs account for nearly one-third of helium demand. Would a significant increase in performance of this technology alone impact prices significantly?

Model improvements and data needs to address the above questions include the following:

- Extending the years covered by the model to include the historical period (1998–2015)
- Data/stakeholder input on developing potential demand scenarios
- Additional data/stakeholder input on potential new natural-gas and helium-only projects, including capital and operating costs
- Minor model adjustments to accommodate these scenarios

In the longer run, additional questions we could answer include the following:

- What are the impacts of a shift from a few big players to a more competitive market with more small players?
- What would be the impacts of different policies for managing the BLM reserve after it is exhausted (e.g., can the reserve still be used for storage)?
- How will helium markets be affected by developments in other markets such as natural gas or oil?
- The DLA is developing a "buyers" group of scientific customers whereby DLA will act as the "broker" for helium purchases by these researchers. At what demand or supply levels does this concept become effective in obtaining lower prices?
- At which point will providers decide that participating in the "in-kind" program is not in their best economic interest and cease participation? What are the primary determinants in such a decision?

Model improvements and data needs to address the above questions include the following:

- Separate rules for helium-only and natural gas projects
- Accounting for natural gas prices in development of those deposits
- Data/stakeholder input on natural gas content of fields and costs and revenues from natural gas production
- Modeling of private use of BLM facilities for storage
- Pricing rules that account for size of buyer (e.g., new contract negotiation rules)
- Expanded modeling of the in-kind program

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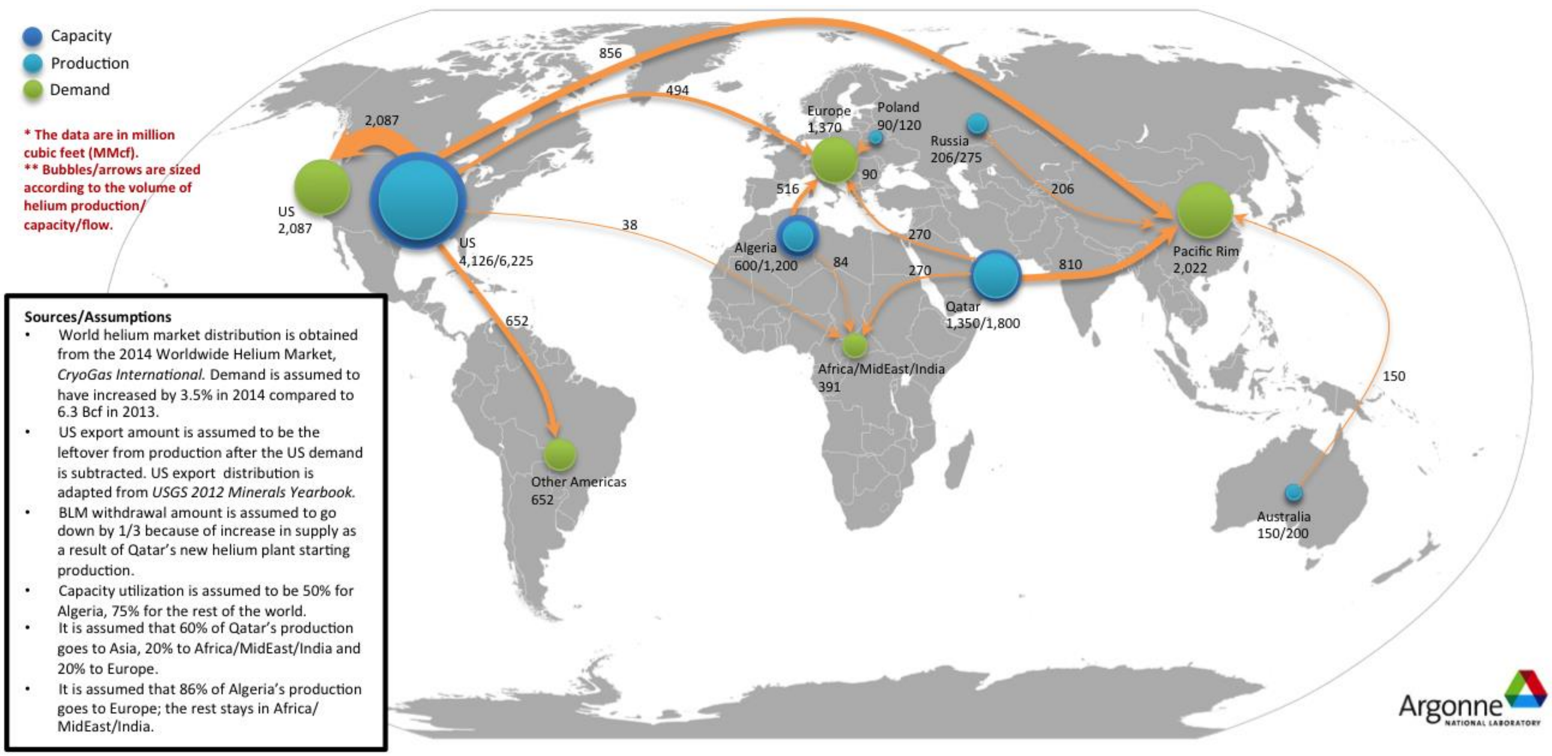
APPENDIX



Appendix: World Helium Capacity/Production/Demand 2014

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